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TITLE: ADDITIONAL SOLAR/LOAD RATIO CORRELATIONS FOR DIRECT GAIN  
BUILDINGS

MASTER

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## ADDITIONAL SOLAR/LOAD RATIO CORRELATIONS FOR DIRECT GAIN BUILDINGS

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## ABSTRACT

Solar/load ratio (SLR) correlations have been developed for two new reference direct gain designs. The new reference designs are identical to the originals<sup>1</sup> except that the glazing air gap has been increased from 1/4 in. to 1/2 in. and a vector average of the local hourly windspeed was used in the thermal network calculations rather than an assumed average value of 15 m.p.h. Both of these modifications are realistic and enhance the predicted performance of direct gain buildings.

A comprehensive set of mass sensitivity calculations has been performed in order to provide information needed to select an appropriate set of parameters for new "lightweight" direct gain designs for which additional SLR correlations will be developed. Representative results are reported herein.

## 1. INTRODUCTION

Correlations between solar savings fraction and solar/load ratio for direct gain and thermal storage wall buildings have been reported in Volume II of the DOE Passive Solar Design Handbook.<sup>2</sup> The reference direct gain designs chosen for study at that time were selected on the basis of compatibility with previously completed studies on thermal storage walls. Since completion of the initial direct gain correlations, a great deal of feedback has been received from other researchers<sup>3</sup> involved in computer simulation of passive solar systems and from the architect/builder community in general. Our own research, in addition to this feedback, has indicated the desirability of developing additional solar/load ratio correlations for direct gain buildings based on the following considerations: (1) the original correlations are unnecessarily conservative because the glazing air gap was set at 1/4 in. (an industry standard) and the windspeed was held constant at 15 m.p.h. (an ASHRAE standard). Unlike thermal storage wall

systems, direct gain buildings are quite sensitive to these two parameters as shown in Fig. 1; (2) the original correlation is based on a very massive structure. In order to match the amount of thermal storage mass in the 18-in.-thick reference design Trombe wall, the reference direct gain design was allowed a 6-in.-thick layer of thermal storage mass spread over an area three times greater than the solar collector area. In fact, many viable direct gain designs are much less massive.

Therefore, solar/load ratio correlations have been developed for two new reference direct gain designs. The new designs are identical to the originals except that the two conservative features have been eliminated. The glazing air gap was

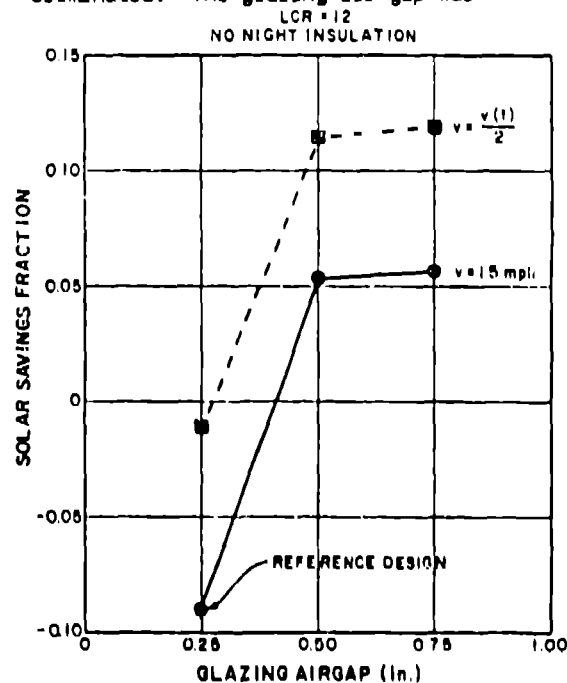


Fig. 1. Sensitivity of performance to glazing air gap and wind velocity in Madison.

<sup>1</sup>Work performed under the auspices of the US Dept. of Energy, Office of Solar Applications.

increased to 1/2 in. and a vector average of the local hourly windspeed was used in the thermal network calculations. Both of these modifications decrease the effective conductance of the solar aperture, thereby reducing heat losses and improving performance.

A second set of new reference designs, which includes the above modifications in addition to a significant reduction in the amount of thermal storage mass, is planned for the near future. In order to aid in selection of appropriate thermal storage mass parameters for the lightweight designs, an extensive set of sensitivity calculations has been performed, and representative results are reported in Section 3 of this paper.

## 2. SOLAR/LOAD RATIO CORRELATIONS FOR THE REVISED DIRECT GAIN DESIGNS

The characteristics of the new reference direct gain designs are:

- o Thermal Storage Capacity = 45 Btu/F ft<sup>2</sup> of glazing.
- o Other thermal mass of building is negligible.
- o Double glazing, with normal transmittance = .747, spacing = 1/2 in.
- o Room temperature control range = 65 F to 75 F.
- o Night insulation (when used) is R9. In place 5:00 p.m. to 7:00 a.m.
- o Thermal mass-to-room air conductance = 1.0 Btu/F hr ft<sup>2</sup>.
- o Masonry properties:
  - k = 1.0 Btu/ft hr F (thermal conductivity)
  - $\rho$  = 150 lb/ft<sup>3</sup> (density)
  - c = 0.2 Btu/lb F (specific heat)
- o Infrared emittance of mass surface = 0.9.
- o No internal heat generation (from appliances, etc.).
- o Mass is 6-in. thick masonry.
- o Mass area is 3 times glazing area.
- o Transmitted solar radiation is uniformly distributed on mass.
- o Non-mass absorption fraction = 0.2 for initially incident solar radiation and each subsequent reflection (heats air directly).
- o Vector average of hourly windspeed used in thermal network calculations.
- o Weather data base is SOLMET TMY for ten US cities.

The new SLR correlations are presented in Figs. 2 and 3 for configurations with no night insulation and R9 night insulation, respectively. The monthly solar savings fraction (SSF) is plotted as a function of S/DD, where S is the transmitted solar radiation per square foot of collection area per month (Btu/month ft<sup>2</sup>) and DD is the monthly heating degree days. The load collector ratio (LCR), which appears as a parameter on both plots, is simply the

building load coefficient (BLC) divided by the solar collection area. The building load coefficient is the additional energy, in Btu/day, required to increase the building temperature one additional degree F, assuming no heat is lost or gained through the solar collection area. The format of the plots appearing in Figs. 2 and 3 was first used in the final version of the Passive Solar Design Handbook.<sup>4</sup> We find this presentation convenient and understandable because the independent variable (S/DD) depends primarily on local weather conditions, while the parameter (LCR) is strictly a property of the building. Thus, the effect of weather conditions and building characteristics on system performance, as represented by the solar savings fraction, are clearly separated.

The solar load ratio correlations for SSF as a function of SLR are represented as follows:

$$SSF = 1 - K \left[ 1 - F(X) \right], \quad (1)$$

where  $F(X) = AX$ , for  $X \leq R$

$$F(X) = B - C \exp(-DX), \text{ for } X > R \quad (2)$$

$$F(X) \leq 1.000 \text{ for very large } X, \text{ and}$$

$$K = 1 + G/LCR \quad (3)$$

$$X = S/DD / (LCR + K) = SLR \quad (4)$$

The relationship between the solar load ratio and the variables used in Figs. 2 and 3, S/DD and LCR, is defined in Eq. (4). Values of the constants for the original direct gain designs (DG and DGN1) and the revised direct gain designs (DGR and DGNIR) are given in Table 1.

TABLE 1  
Correlation Constant for Reference Direct Gain Designs

System	G	R	A	B	C	D	$\sigma$
DG	10.6	0.5	0.321	1.013	1.064	0.693	.046
DGN1	2.4	0.7	0.342	0.987	1.148	0.910	.035
DGR	8.64	0.7	0.311	1.002	1.141	0.815	.045
DGNIR	2.04	0.9	0.316	0.986	1.259	0.979	.034

The revised direct gain performance curves in Fig. 1 indicate that positive solar savings fractions can be achieved during a given month at any location without night insulation when S/DD is greater than about 17 for load collector ratios greater than 20. The original design required an S/DD greater than 21 for load collector ratios greater than 25 in order to yield positive SSFs. Thus, the more realistic revised direct gain design yields significant increases in predicted performance. The increases are more pronounced at small load collector ratios because performance is more sensitive to the decrease in the effective conductance of the solar aperture when that

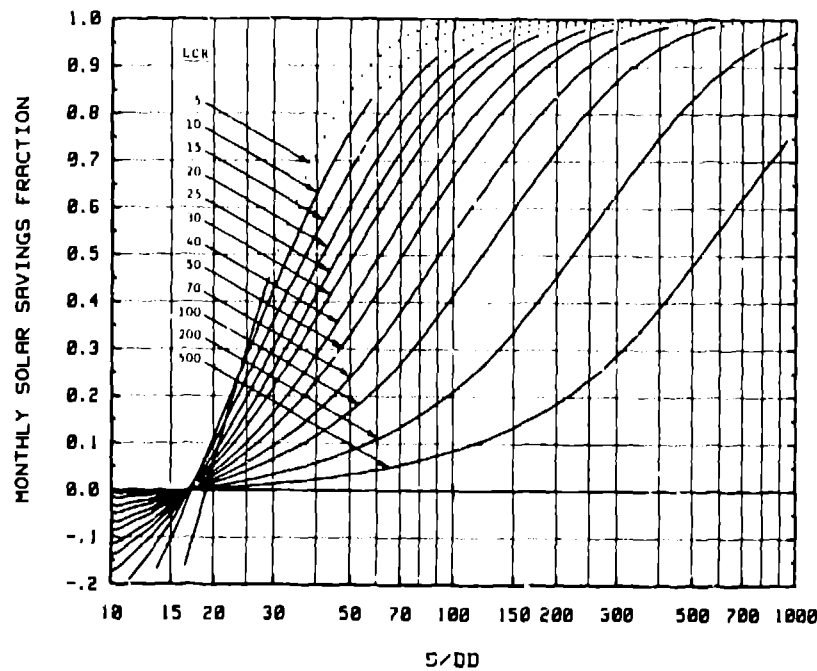


Fig. 2. Monthly performance curves for revised direct gain systems with no night insulation.

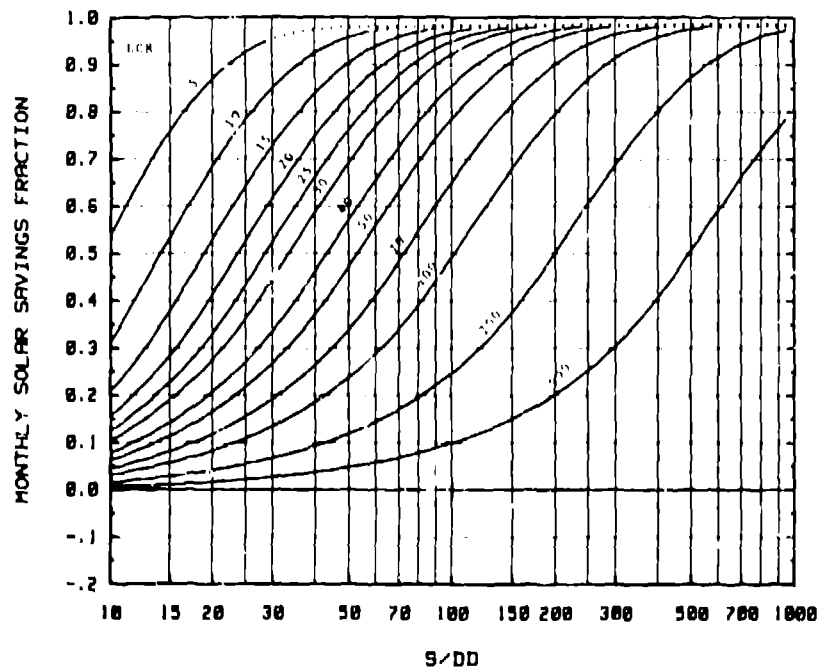


Fig. 3. Monthly performance curves for revised direct gain systems with R9 night insulation.

aperture is large relative to the building load coefficient. Similarly, performance increases are slightly more pronounced in harsh climates where monthly values of  $S/DD$  are generally small. The enhancement occurs in harsh climates because the effect of variations in effective aperture conductance

is more keenly felt in cold high  $DD$  locations than in warmer low  $DD$  locations. When R9 night insulation is employed on the revised direct gain design, however, the change in predicted performance compared to the original night insulated design is much less dramatic. In fact, except at very low

values of LCR and S/DD, the differences are insignificant. This result was expected because the presence of R9 night insulation for fourteen hours during the coldest part of each day masks the relatively small effects due to varying the air gap and the windspeed.

### 3. SENSITIVITY OF PERFORMANCE TO VARIATIONS IN THE THICKNESS AND SURFACE AREA OF THERMAL STORAGE MASS

The solar savings fraction is plotted as a function of thermal storage mass thickness for three cities, Santa Maria, Albuquerque, and Madison, and for two configurations, with no night insulation and with R9 night insulation, in Figs. 4 through 9. The three cities selected are considered representative of locations exhibiting mild, moderate, and severe winter climates, respectively. The load collector ratio was held constant at 12 except in Santa Maria, where a value of 24 was judged more realistic. Four mass surface-to-glazing surface area ratios ( $A_m/A_g = 2, 3, 6, 10$ ) are included on each graph and the reference designs (thickness = 6 in.,  $A_m/A_g = 3$ ) are indicated by solid points.

It is difficult to generalize on the basis of so large a quantity of data as included in Figs. 4 through 9, but, after careful inspection, some significant patterns do emerge.

- o Performance variations for mass thicknesses between 4 in. and 8 in. are small. An earlier study<sup>5</sup> showed that maximum solar savings fractions are achieved at a thickness of about 8 in. The present study indicates that the thickness may be reduced to 4 in. without incurring significant performance penalties. This generalization is independent of location, configuration, and mass surface area.
- o The range of mass thicknesses between 2 in. and 4 in. can be considered a transition region. In this region, performance penalties for reduced thicknesses are becoming significant, but may be considered acceptable as design cost trade-offs.
- o For mass thicknesses below 2 in., performance falls off much more rapidly than in the transition region. Under most conditions it is not advisable to employ mass thicknesses of less than 2 in., particularly if one is striving for a high solar savings fraction.

It would be a mistake to assume that all points on the sensitivity curves represent designs that can be achieved in practice. In particular, the high  $A_m/A_g$  ratios may not be obtainable if the glazing area is quite large or, equivalently, if the load collector ratio is small, as it is in these

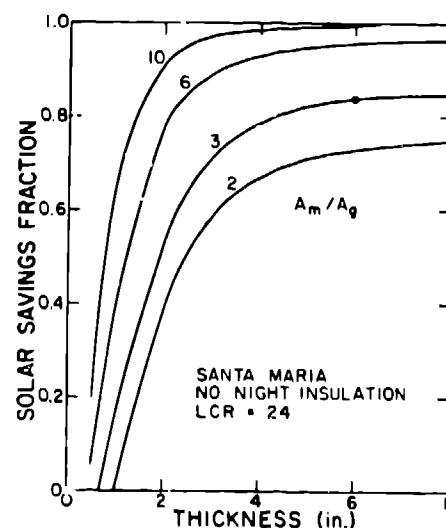


Fig. 4. Solar Savings Fraction vs Thickness.

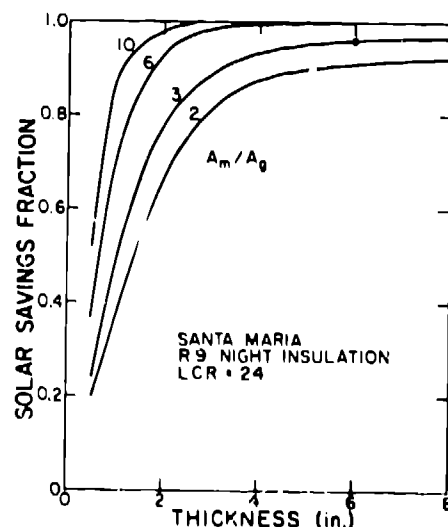


Fig. 5. Solar Savings Fraction vs Thickness.

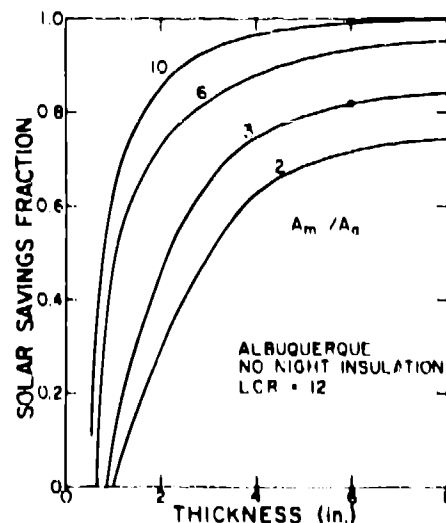


Fig. 6. Solar Savings Fraction vs Thickness.

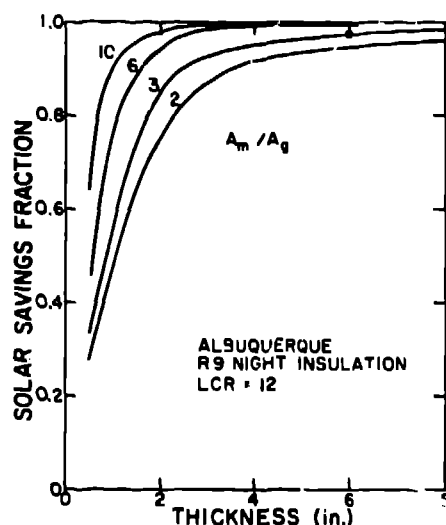


Fig. 7. Solar Savings Fraction vs Thickness.

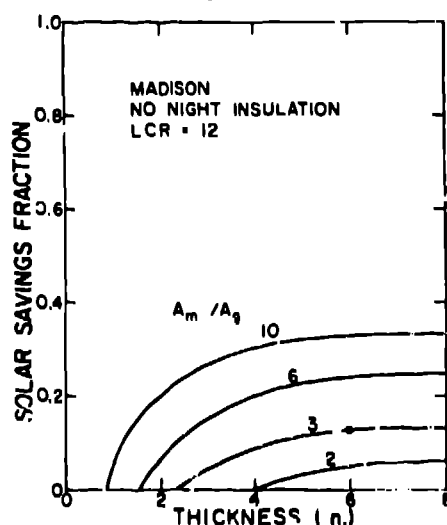


Fig. 8. Solar Savings Fraction vs Thickness.

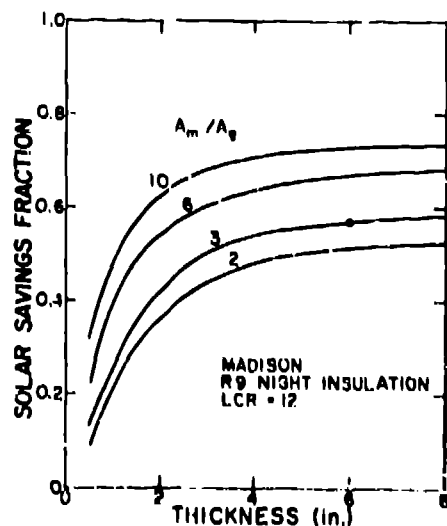


Fig. 9. Solar Savings Fraction vs Thickness.

figures. There may simply not be enough surface available on which to place the mass. This problem is aggravated by the fact that only mass that is located in building zones that experience direct solar gains can be credited to the system. Thus, surfaces in northern zones are unavailable to the system unless illuminated, for example, by clerestory windows.

#### 4. CONCLUSIONS

The performance of direct gain buildings shows significant sensitivity to glazing air gap and wind velocity. For this reason, new solar/load ratio correlations have been developed and presented. The new correlations employ an air gap of 1/2 in. rather than the original 1/4 in. and use a vector average of the actual windspeed rather than an assumed constant value of 15 m.p.h. Both of these changes yield small, but significant, increases in performance.

A comprehensive set of mass sensitivity calculations has been presented in graphical form. The results indicate that, generally, thermal storage mass in direct gain buildings should be at least 2 in. thick if one is designing for high solar savings and not more than 6 in. thick if one is concerned about cost effectiveness. New SLR correlations for 2-in.-thick mass configurations are planned for the future. The new correlations, together with the ones presented in this paper, will bound the range of recommended mass thicknesses for direct gain buildings.

#### 5. ACKNOWLEDGMENT

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